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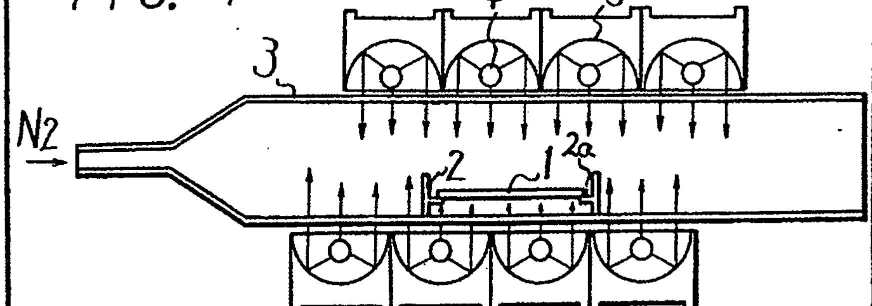
(54) Processes for Manufacturing Semiconductor Devices

(57) A process for manufacturing a semiconductor device includes the steps of implanting impurity ions in a surface of a semiconductor substrate 1, and irradiating the substrate 1 with incoherent light with lamps 4 which irradiate an area greater than that of the implanted surface of the substrate 1, whereby the implanted region is electrically activated. Tungsten-halogen lamps may be used.

FIG. 1



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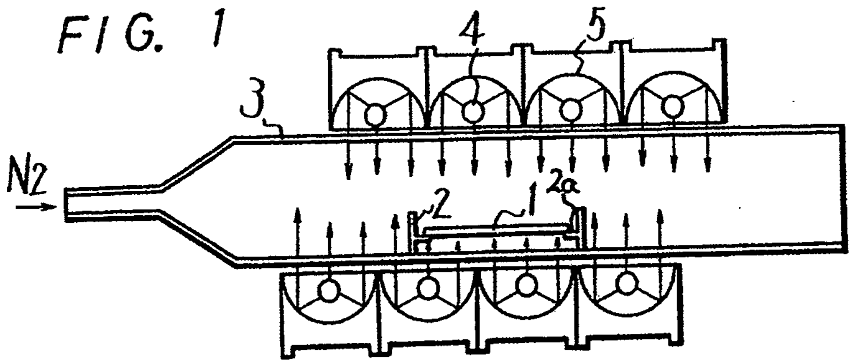
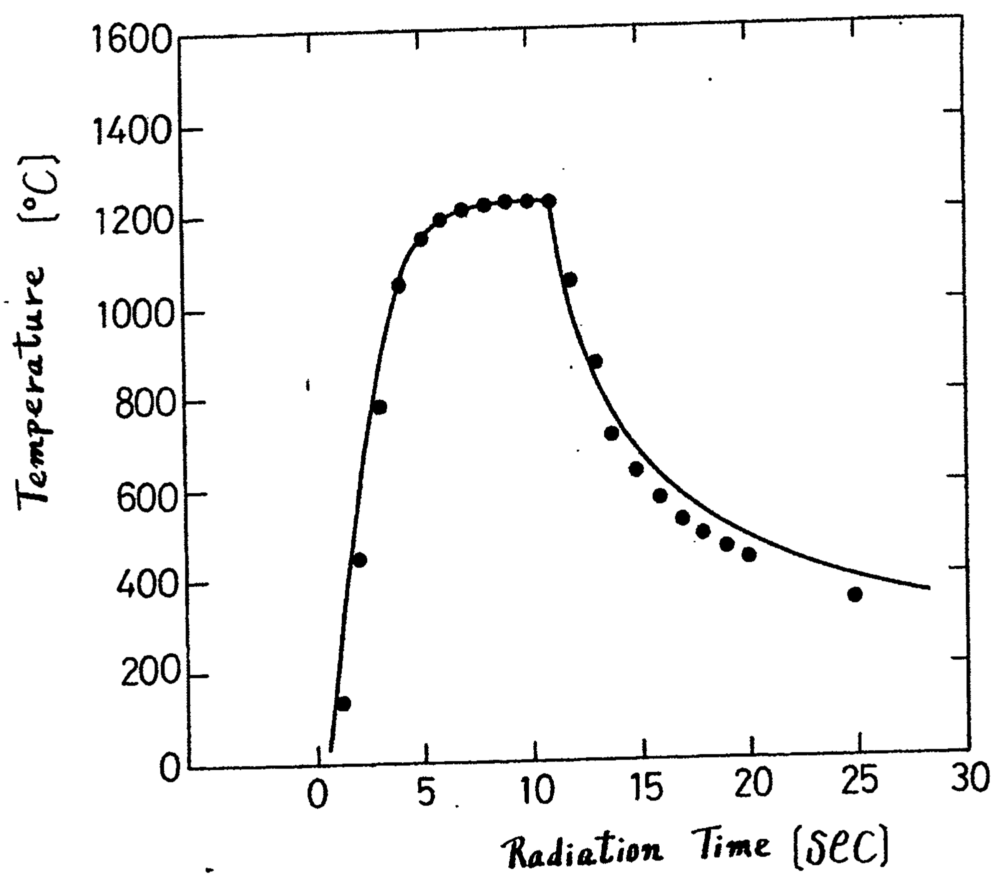
The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy

FIG. 1



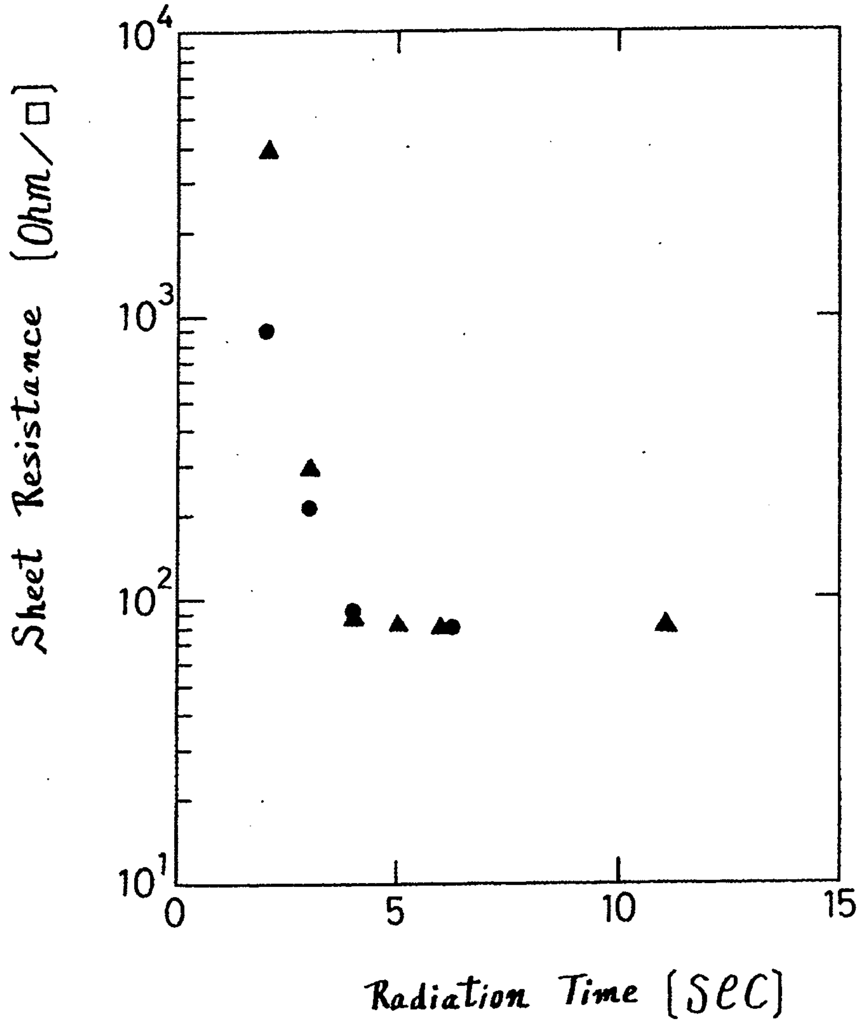
4
5
3
N2
2
1
2a

FIG. 2



1600
1400
1200
1000
800
600
400
200
0
Temperature [°C]
0
5
10
15
20
25
30
Radiation Time [SEC]

FIG. 3



Sheet Resistance [Ohm/□]
10^4
10^3
10^2
10^1
0
5
10
15
Radiation Time [sec]

FIG. 4

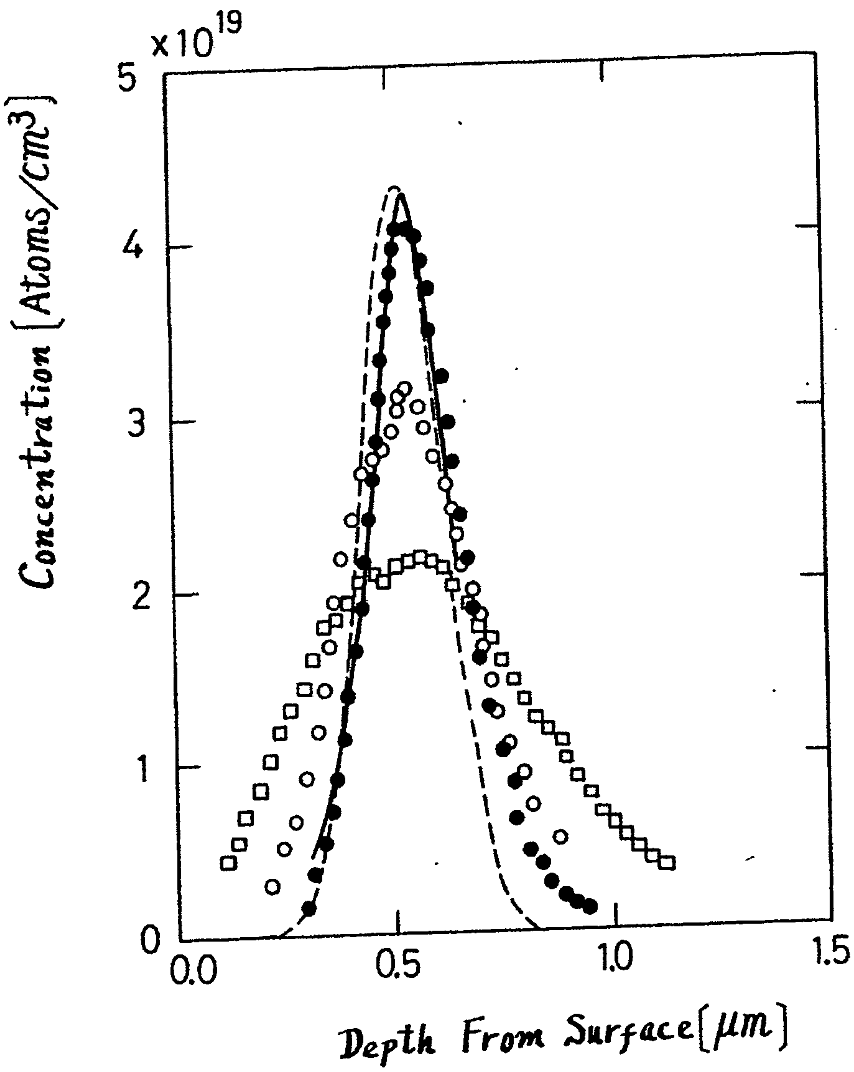
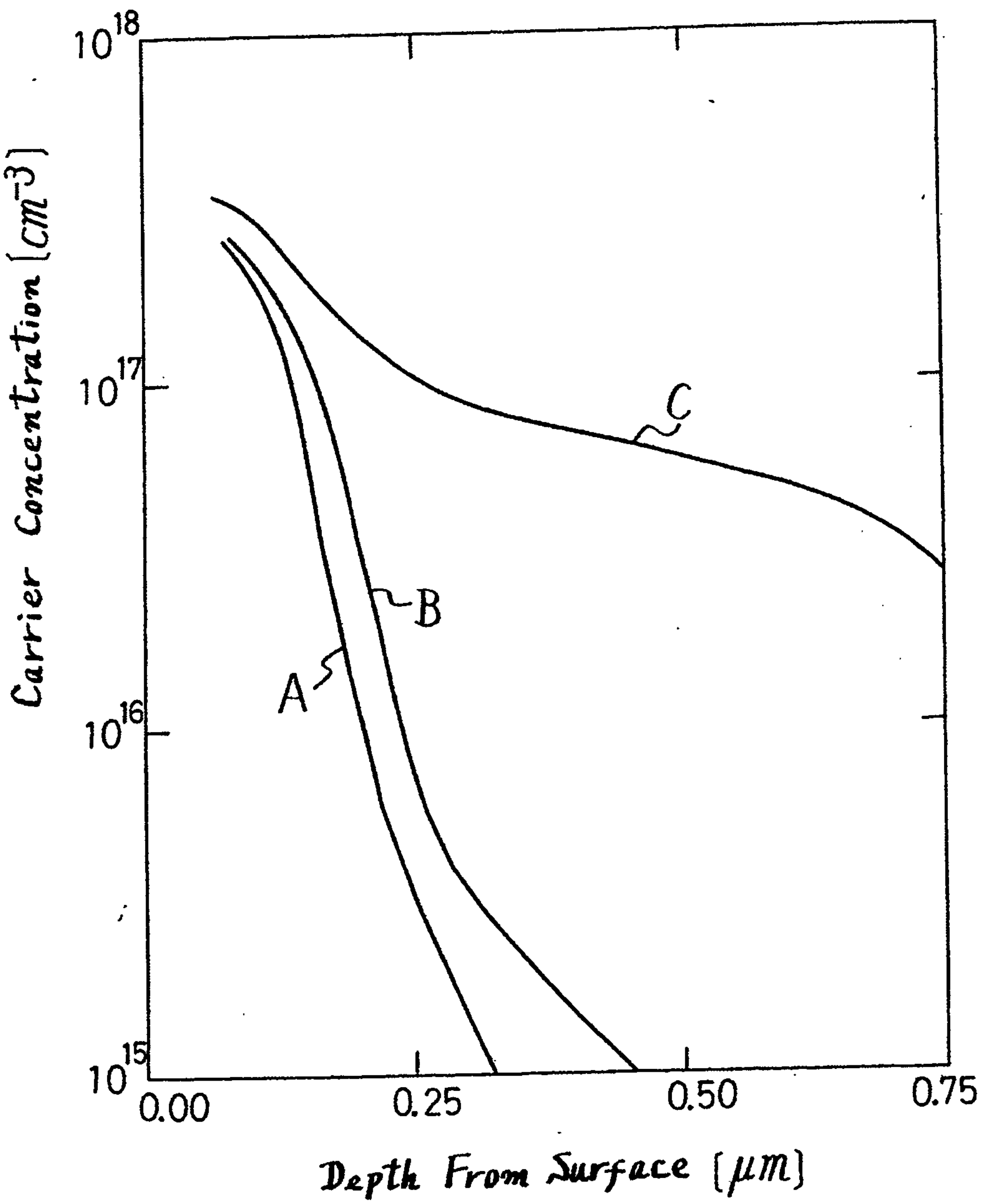

x10^19
5
4
3
2
1
0
Concentration [Atoms/cm^3]
0.0
0.5
1.0
1.5
Depth From Surface [μm]

FIG. 5



10^{18}
10^{17}
10^{16}
10^{15}
Carrier Concentration [cm^{-3}]
C
B
A
0.00
0.25
0.50
0.75
Depth From Surface [μm]

SPECIFICATION

Processes for Manufacturing Semiconductor Devices

This invention relates to processes for manufacturing semiconductor devices and to semiconductor devices manufactured by such processes.

To remove crystal defects in an ion implanted region of a semiconductor it is known to activate the implanted atoms or ions electrically by annealing in an electric furnace. In such a process a plurality of semiconductor substrates implanted with ions are set on a quartz board or the like and then they are subjected to the heating process in the furnace, for example at 800 to 1200°C for more than ten minutes, to provide an electrically activated region in each of the substrates.

This method is productive, because a plurality of substrates can be processed at the same time, but defective because of the fact that since the substrates to be annealed have large thermal capacities, non-uniformities occur in the electrically activated layers.

Moreover, in the case where the profile of an ion implanted region is to be utilized in making a semiconductor element, some redistribution affecting the ion implantation profile occurs if the heating is too prolonged.

Also, if the semiconductor is thermally unstable, such as gallium arsenide, then atoms of the substrate may be vapourized by prolonged heating at high temperature, resulting in a thermal conversion layer on the surface of the substrate which damages the electrical activation of the ion implanted region.

Recently, a new annealing process for an ion implantation region, using a laser has been studied. Such a process can electrically activate an ion implanted region in a very short period of time, for example in the nanosecond to microsecond range. The substrate absorbs the energy of the incident laser light and converts it to heat energy to achieve the annealing process. The light absorption coefficient of the substrate is, however, very dependent on the wavelength of the laser light used, and also on the crystal properties of the semiconductor substrate (which further varies in dependence on the amount of implanted ions). This means that the laser output must be changed depending on the particular substrates to be annealed.

Moreover, problems arise when a laser beam impinges on a multilayer structure such a silicon dioxide-silicon structure, or polycrystalline silicon-silicon structure, because of reflection of the laser light on, for example, the surface of the silicon, and consequent interference effect dependent on the wavelength of the laser light, the thickness of a silicon dioxide layer on silicon and so on.

In the process using laser light, a laser beam focussed to a spot several tens of microns across scans a semiconductor substrate in two dimension to anneal it uniformly. However, uniform annealing tends not to be achieved due to fluctuation of flickering of the laser light. Moreover, to irradiate a semiconductor substrate with a large spot requires a very large laser output.

According to the present invention there is provided a process for manufacturing a semiconductor device, comprising:

implanting impurity ions in a surface of a semiconductor substrate; and

radiating incoherent light on an area which includes all said surface and more, whereby the implanted region is electrically activated.

The invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a cross-sectional view showing an example of heating apparatus of a uniform radiation type which uses mirrors each having a parabolic reflecting surface, and usable for carrying out a process according to the invention;

Figure 2 is a graph showing the temperature to radiation characteristic of a semiconductor wafer in the heating apparatus of Figure 1;

Figure 3 is a graph showing the relation between the time of irradiation on a semiconductor wafer and the sheet resistance thereof;

Figure 4 is a graph showing the boron concentration profile of a (111) surface semiconductor wafer; and

Figure 5 is a graph showing the carrier concentration profile semiconductor wafer in which thermal conversion appears.

Figure 1 shows in cross-section a heating apparatus comprising parabolic reflecting mirrors and producing incoherent light radiation. A semiconductor wafer 1 in which ions have been implanted is supported by a ring-shaped support 2 made of quartz which supports the semiconductor wafer 1 through, for example, three or four thin projections 2a so that the wafer 1 can be effectively heated. Two wafers 1 may be superimposed with their front or back surfaces in contact with each other and supported by the support 2. The support 2 is housed in a quartz tube 3 of rectangular cross-section which can accommodate a plurality of supports 2 if required. Radiation lamps 4, continuously emitting light from heated refractory metal, for example, tungsten-halogen lamps, radiate visible and infrared light with wavelengths of 0.4 to 4 microns and have respective parabolic mirrors 5 so as to produce substantially parallel light beams. Respective sets of lamps 4 with their mirrors 5 are located above and below the quartz tube 3 along the longer sides of the quartz tube 3. In this example, four lamps 4 and mirrors 5 are located on each of the upper and lower sides of the quartz tube 3, and the lamps 4 and mirrors 5 above and below the quartz tube 3 are complementarily displaced so as uniformly to irradiate the substrate 1. It will also be noted that the area irradiated exceeds that of the substrate 1.

In use, nitrogen is passed through the quartz

tube 3 at a flow rate of 21/min to prevent oxidization of the wafer 1. It should also be noted that the light absorption coefficient of quartz is low, so there is little heating of the wafer 1 as a result of the radiation from the quartz tube 3, as occurs in an ordinary electric furnace, so that contamination by sodium ions or the like is reduced. With the heating apparatus of Figure 1, the wafer 1 can be heated much more rapidly than by thermal conduction in an electric furnace.

As will be apparent from the graph of Figure 2 which shows the temperature rise of the above heating apparatus, the temperature on the wafer 1 arrives at 1200°C within about six seconds from the start of light radiation. In the case of the graph of Figure 2, the input power is 20 Wcm^{-2} and the emissivity is 0.5, and the black dots represent experimental values, while the line shows a theoretical value. Therefore, the radiation time need only be about 10 seconds, and moreover the temperature can be determined by the radiation time period. Thus, it is unnecessary to control the temperature by using a thermocouple. Also, because only wafer 1 is heated the sheet resistance thereof remains uniform and there is little tendency for the wafer 1 to warp.

As alternatives to the above heating apparatus, a heating apparatus may be used in which a semiconductor wafer moves continuously through the radiation area along an air-cushioned track, or a heating apparatus may be provided integrally with an ion implanting apparatus so that ions are implanted in a semiconductor wafer and thereafter the wafer is annealed in the same chamber. Moreover, in place of the parabolic mirrors 5, mirrors with elliptical reflecting surfaces may be used to focus the light.

The annealing time occupies only a matter of seconds, so that the ion implanted region can be electrically activated without redistribution, and a shallower junction can be formed.

When a semiconductor device such as a gallium arsenside device which is thermally unstable is manufactured, the ion implanted region can be activated in a short time period by the light radiation, so the vapourization of gallium or arsenic, or the diffusion of chromium can be suppressed, so the generation of a thermal conversion layer is avoided and the impurity profile produced by the ion implantation is not damaged.

When annealing using incoherent light radiation is applied to a multilayer semiconductor wafer such as silicon dioxide-silicon structure or a silicon polycrystalline silicon structure, since the wavelength of the tungsten-halogen lamp light is in the range of 0.4 to 4 microns, the wave interference effect, which causes a problem in laser annealing is avoided.

Experimental Example 1

In the surfaces (100), (111) of a Czochralski crystal wafer of N-type silicon are implanted B^+ ions at an energy of 200 KeV and a dosage of $10^{15}cm^{-2}$. Then the wafer is radiated using tungsten-halogen lamp light in the heating apparatus of Figure 1, with a lamp input of 35 W cm^{-2}.

Figure 3 is a graph showing the relation between the light radiation time and the sheet resistance of the wafer surface. In the graph of Figure 3, the black dots show the wafer with (100) surface and a resistivity of 40 to 80 ohm cm and the black triangles show the wafer with the (111) surface and a resistivity of 60 to 80 ohm cm.

With electric furnace annealing, for example, at 1100°C and for fifteen minutes, the sheet resistance of a semiconductor wafer is about 80 ohm per unit area. Therefore, it will be understood that a semiconductor wafer having characteristics similar to that produced in an electric furnace can be produced by the radiation of light for about six seconds.

Figure 4 is a graph showing the concentration profile of boron in the (111) surface of a semiconductor wafer. The solid line represents the profile as implanted with boron, and the broken line represents the theoretical value. In this graph the black dots show the case where the light is irradiated on the wafers for six seconds, while the white dots and rectangules show the cases where the wafers are heated at 1000°C and 1100°C for fifteen minutes in an electric surface. It will be seen that little rediffusion of impurities occurs when annealing with light, and the distribution of the sheet resistance within the wafer is within 1.2%.

Experimental Example 2

Si^+ ions are implanted in a wafer of gallium arsenide doped with chromium with an energy of 70 KeV and a dosage of $3\times10^{12}cm^{-2}$, and tungsten-halogen lamp light is irradiated on the wafer using the heating apparatus of Figure 1. In this case, the gallium arsenide wafer is placed on a substrate such as of silicon, which has smooth surfaces, absorbs the radiated light and is suspended by the quartz support 2 as in Figure 1, with its implanted surface down and contacting the upper surface of the silicon substrate. In this way the heat is conducted to the gallium arsenide wafer and evaporation for example of arsenic is prevented.

In the case of gallium arsenide wafers doped with chromium, excess carriers are generated by diffusion out of chromium and N-type thermal conversion is apt to be generated therein.

Figure 5 is a graph showing the comparison of carriers profiles of wafers which are particularly prone to be thermally converted. Curves A and B respectively show cases of light irradiation up to 940°C at which instant the radiation is stopped, and of light radiation up to 900°C at which temperature the radiation is maintained for ten seconds, while a curve C shows the case where a wafer is heated in an electric furnace at 850°C for fifteen minutes. From the graph of Figure 5 it will be understood that when annealing with light few

excess carriers are generated, and the carrier profile is sharp.

The above heating apparatus can also be used for a heating process in which an insulating layer for passivating the surface of a gallium arsenide wafer during annealing is formed before annealing. In this case, silicon hydride (SiH_4) and O_2 are introduced into the quartz tube of the heating apparatus in which the wafer is located, and when the gas flow has become stable light is radiated on the wafer to heat it to 400 to 500°C for several seconds thereby to make a silicon dioxide layer by chemical vapour deposition on the surface of the wafer. This wafer is then subjected to the anneal heating in the same quartz tube.

The invention can also be applied to a process in which ions are implanted into a wafer at higher dosages to prevent the diffusion of atoms from a metal layer, which serves such as an ion implantation mask or a contact conductor.

Claims

1. A process for manufacturing a semiconductor device, comprising: implanting inpurity ions in a surface of a semiconductor substrate; and radiating incoherent light on an area which includes all said surface and more, whereby the implanted region is electrically activated.

2. A process according to claim 1 wherein said light is continuously emitted from a heated refractory metal.

3. A process according to claim 1 wherein said substrate is suspended such that both of major surfaces are exposed to said light.

4. A process according to claim 1 wherein said surface of said substrate is placed in contact with a wafer which absorbs said light and is supported with the surface opposite to that contacting said substrate exposed to said light.

5. A process for manufacturing a semiconductor device, the process being substantially as hereinbefore described with reference to Figure 1 of the accompanying drawings.

6. A semiconductor device made by a process according to any one of the preceding claims.

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